FUEL EFFICIENCY BOOKLET 15

Economic use of gas-fired boiler plant

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

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INTRODUCTION

1 INTRODUCTION

Steam and pressurised hot water boiler plants in industry and commerce vary in capacity from 100 kW to over 30 MW (341,000 BTU/h to over 102 million BTU/h). This booklet relates mainly to shell boilers, i.e. those covering the middle range of capacity, of which there are many thousands in operation for heating and process applications. Much of the information is also relevant to other types of boiler.

The booklet provides guidance on the ways in which gas and therefore money can be saved in the operation of boiler plants. The approach used examines the plant from gas delivery progressively through to the final heat output, and identifies and quantifies the various losses. Finally, there is a check list of money-saving procedures followed by a summary of further information with contact addresses, collating references throughout the text.

In order to show savings in perspective, reference is made to an example plant having a gas bill of £285,000 per year. Individual cases obviously need their own examination, but nevertheless it is hoped that the inclusion of a quantitative example will help to give an indication of the possible savings that users can make.

Many boiler plants are operating at lower efficiencies than can be achieved and, moreover, maintained. The potential savings in gas can be worthwhile. This booklet will tell you how to obtain them.

2 BACKGROUND INFORMATION

Gas supply

Where gas is supplied via the national distribution system, the user's responsibility for the supply commences downstream of the main meter installation. Where the outlet downstream supply pressure is boosted, maintenance and running costs of the booster should be checked. Otherwise only pipe maintenance costs need be taken into account.

Metering of gas supplies to boilers should be considered. If a single boiler is the only consumer of gas, then the main incoming supply meter can be used to monitor consumption on a daily or weekly basis, as required. The supply meter can also be used to compute the instantaneous inputs. Individual sub-meters are preferable where there are several boilers installed, as they provide a means of monitoring the fuel consumption of individual boilers. Furthermore, recorded meter readings will highlight changes in consumption, and will identify wastage of fuel associated with boiler inefficiencies or steam losses.

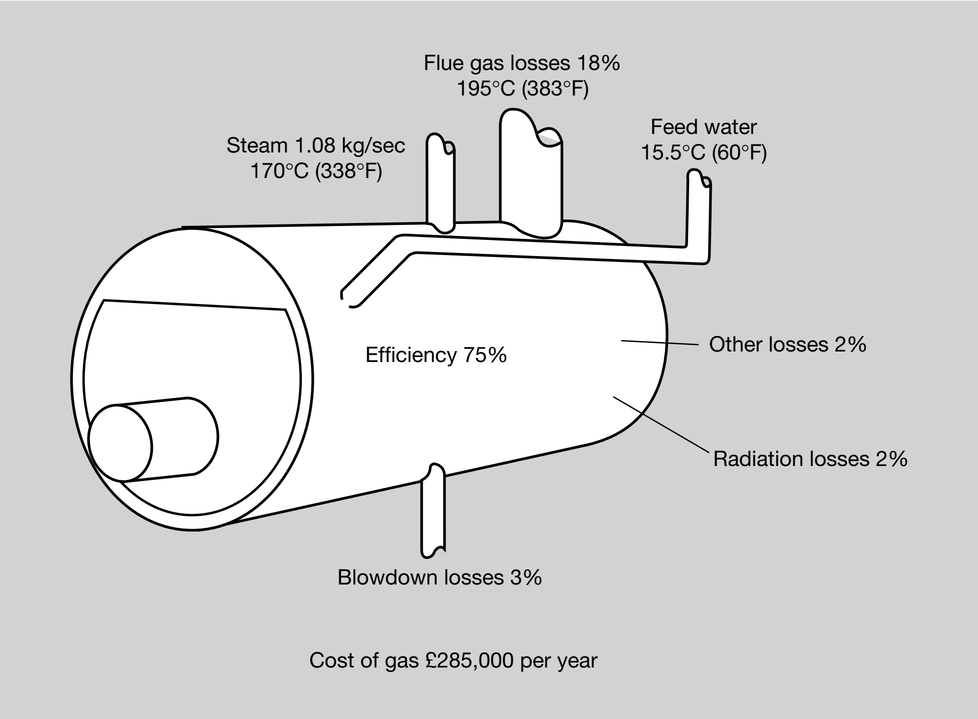
Other fuel gases, for example liquid petroleum gases (i.e. Propane), may require storage and delivery facilities and entail other costs, which will need individual assessment.

Pollution control

Energy savings cannot be looked at in isolation and must not be achieved at the cost of increased waste emissions.

BACKGROUND INFORMATION

Fig 1 Example Boiler



Depending on their size, boilers are dealt with by either the *Clean Air Act* Regulations or the *Environmental Protection Act*. Boilers under 20 MW come under the *Clean Air Act*, whilst boilers in the size range 20 - 50 MW are covered by Part B of the *Environmental Protection Act* (EPA). The Environment Agency is now responsible for larger boilers where aggregated fuel inputs exceed 50 MW on a net calorific value basis.

With the implementation of the EPA, a requirement for BATNEEC (best available techniques not entailing excessive cost) is now enforced, replacing the previous ‘best available means’. In setting emission limits, the Environment Agency takes into account the cost of installing further pollution abatement equipment. If this is viewed to be excessive, then additional control may not be required.

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Example boiler

An Example Boiler is used in the following sub-sections to illustrate the significance of savings

The boiler efficiency of 75% has been chosen so that improvements can be suggested. No doubt many boilers do not attain this level of performance, but a well-operated shell boiler of modern design can be expected to have a thermal efficiency in excess of 80% at its designed output. The Example Boiler details are as follows:

Boiler efficiency based on gross calorific value:	
Flue gas losses	18%
Radiation losses	2%
Blowdown loss	3%
Other losses	2%
Boiler efficiency	75%
Flue gas temperature	195ºC (383ºF)
Feed water/boiler water	15.5ºC (60ºF)
Return temperature	Assumes mains water at 8ºC (47ºF) and 25% condensate return at 38ºC (100ºF)
Steam production (approx)	1.08 kg/sec (8,000 lb/h) 7,000 hours per year*
Steam pressure	7 barg (100 psig)
Steam temperature	170ºC (338ºF) (dry saturated)
Cost of gas	£285,000 per year (32p per therm)

** For a boiler to maintain a continuous output for 7,000 hours per year may of course be unrealistic from the operational point of view; however the foregoing details have been chosen to provide a simple basis for making comparisons.*

Boiler thermal efficiency

Minimum costs are achieved by running boilers at high thermal efficiency. This section examines the various heat losses and draws attention to how they can be minimised.

Heat losses from boilers include: losses from the flue gases (referred to as flue gas losses); losses from exposed boiler surfaces (referred to as radiation losses); and losses through water blowdown (referred to as blowdown losses). These losses can be expressed in the form of a basic equation :

Boiler thermal efficiency % =
100% - (flue gas losses % + radiation losses % + blowdown losses %)

Calculations in this booklet are based on the gross calorific value of the fuel. When heat content of fuels or boiler efficiencies are quoted, it is important to indicate whether they are given on a gross or net basis. It is essential to understand the difference between these terms.

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Savings or losses due to changes in efficiency

Simple calculations reveal possible savings or losses due to changes in efficiency. Given the efficiency values, the effect on the fuel cost is as follows:

$$\text{Change in fuel cost} = \text{original fuel cost} \times \frac{\text{new efficiency} - \text{original efficiency}}{\text{new efficiency}}$$

Taking the Example Boiler with an efficiency of 75%, if the efficiency is raised by 4% to 79% the saving would be:

$$\text{Fuel cost saving} = £285{,}000 \times \frac{79 - 75}{79} = £14{,}430 \text{ per year}$$

If a boiler with the same fuel consumption as the Example Boiler had an efficiency of only 50%, then an increase in efficiency to 54% would give a greater saving:

$$\text{Fuel cost saving} = £285{,}000 \times \frac{54 - 50}{54} = £21{,}111 \text{ per year}$$

All fuels contain some hydrogen which when burned produces water in the form of steam. The latent heat in this steam is not recovered unless condensation occurs. The gross calorific value includes all of the available heat of combustion, whereas the net value is the gross value less the heat in the water vapour (latent heat of vaporisation). When gross calorific values are used as the basis for calculating efficiencies in the above equation, the flue loss item includes the heat in the steam; when net calorific values are used this heat loss is excluded. For this reason a boiler efficiency calculated on a net basis is numerically higher than that on a gross basis, although the actual heat output is identical.

Net values are frequently used in most European countries.

For the calculations in this booklet, the gross calorific value is used because it is the simplest to correlate to fuel costs which are charged on a gross basis. The difference between gross and net value is approximately 10%.

Flue gas losses

■ *Fuel-to-air ratio*

To achieve a high thermal efficiency and thereby minimise fuel costs, the amount of combustion air should be limited to that necessary to ensure complete combustion of the gas, including a margin of excess air to suit the particular combination of burner and boiler.

Heat is transported to the flue by the excess air. Consequently, if the air rate is too high the

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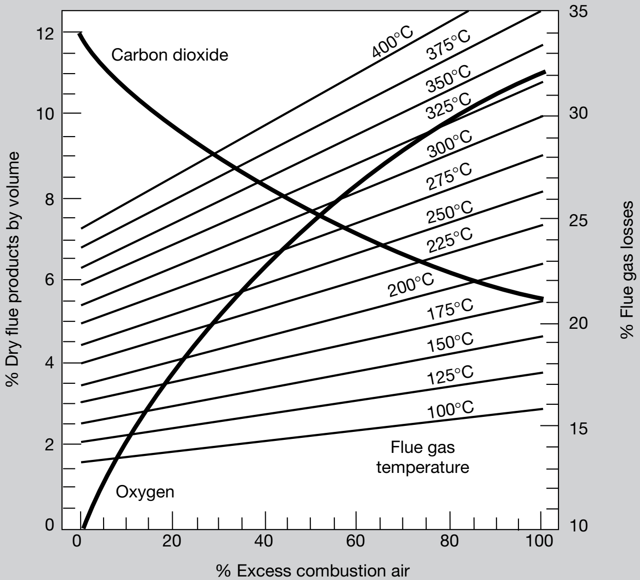
loss of heat to the flue, and therefore the running cost, will increase. Similarly, if the air rate is too low a proportion of the fuel will remain unburnt, smoke will be produced possibly breaching pollution regulations, and the running cost will again be increased. The type of burner, its controls and adjustment will determine the results that can be achieved: the boiler and burner supplier should be consulted to establish the best settings.

Traditionally, modulating burner fuel-to-air ratios are controlled by characterising cams and connecting linkages. These are subject to wear and tear, and it is important that repairs and adjustments are undertaken on an on-going basis. Furthermore, where dual-fuel burners are in operation, any changeover from one fuel to another necessitates recommissioning of fuel-to-air ratios, to ensure that combustion efficiency is not adversely affected. Modern technology enables fuel-to-air ratios to be maintained at all times. Microprocessor controlled servo motors fitted to fuel valves and air dampers replace the traditional methods of control, providing a programmable system which will automatically select and maintain the fuel-to-air ratio specific to a particular fuel.

To check that the fuel-to-air ratio is correct, the usual method is to analyse the flue gases leaving the boiler. By determining the composition and temperature of these gases, the loss of heat to the flue can be assessed. The loss can be calculated using equations, such as those in BS 845: 1987 - *Methods for assessing thermal*

Fig 2 Flue gas losses - natural gas



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performance of boilers for steam, hot water and high temperature heat transfer fluids; alternatively, loss values can be read from reference charts, such as those shown in Figs 2, 3 and 5. These charts are sufficiently accurate for the aims of this booklet. In the charts the dry flue gas product is measured at ambient temperatures, and the flue gas loss values are based on gross calorific value of the gas.

The charts do not show the losses incurred by running with a deficiency of combustion air. Any boiler found to have significant quantities of combustible gases in the flue products, should immediately have its controls reset: such a condition not only wastes fuel, but can also be dangerous.

It should be noted that recent burner control developments are able to maintain a more accurate and consistent fuel-to-air ratio over the full range of burner operation. There are also systems which automatically compensate for changing conditions. For example, oxygen trim controllers will continually monitor the level of oxygen in the flue gases and make corrections to the combustion air supply so optimum boiler performance is maintained. The cost benefits of the various possibilities should be evaluated and compared.

It is important to realise that fuel wastage due to an inaccurate fuel-to-air ratio is not readily apparent - it is not like a steam leak or an obviously overheated building. Particular attention should therefore be given to flue gas analysis, preferably on a regular basis.

■ *Flue gas analysis*

Typical conditions for efficient gas-fired shell boilers are about 15 - 30% excess air resulting in 9 - 10% carbon dioxide (CO_2) and 3 - 5% oxygen

Savings or losses due to flue gas composition change, showing the significance of the fuel-to-air ratio

In the Example Boiler, 20% excess air is required to give 18% flue gas loss, as quoted in the specification. If excess air was reduced to 10%, the percentage of CO_2 in the flue gas at 195ºC (383ºF) would increase from 9.75% to 10.7% and the flue gas losses would be reduced to 17.4%. The boiler efficiency would be improved by 0.6% to 75.6%, resulting in a saving in the fuel bill of:

$$£285{,}000 \times \frac{(75.6 - 75)}{75.6} = £2{,}262 \text{ per year}$$ (see Fig 4).

If, however, the excess air was increased to 44%, the percentage of CO_2 in the flue gas at 195ºC (383ºF) would fall from 9.75% to 8%, the flue gas losses would rise and the boiler efficiency would fall by 1.3% to 73.7%. This would result in an increase in the annual fuel bill of:

$$£285{,}000 \times \frac{(73.7 - 75)}{73.7} = £5{,}027 \text{ per year.}$$

These examples are illustrated on Fig 3 to show how the graph is used

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(O_2) in the flue gases. When analysing flue gases the level of carbon monoxide (CO) content may also be measured, giving an indication of incomplete combustion.

Test equipment is available for analysing the flue gases and measuring their temperature, costing around £1,000 to £2,000 upwards. This type of equipment is adequate for regular checking purposes. There are several portable analysers available which automatically compute boiler efficiency, giving flue gas temperature, excess air, carbon dioxide and efficiency values at the touch of a button. The greater expense of a permanent installation or the use of more expensive equipment may be justified for larger plant, or at installations where there are several boilers.

When using analysing equipment, it is most important that the manufacturer's operating instructions are complied with and that the instruments are properly serviced. For example, flue gas samples should not be diluted by air inleakage which would give misleading results, and all sample points should be thoroughly purged before aspirating the sample to ensure that the line is free from air and not obstructed.

The sampling point in the boiler flue should be as close to the boiler as practicable. Checks should be made to ensure that the sample is representative, by traverse testing. On some old-

Fig 3 Flue gas losses - natural gas - Effect of reduction and increase of excess air

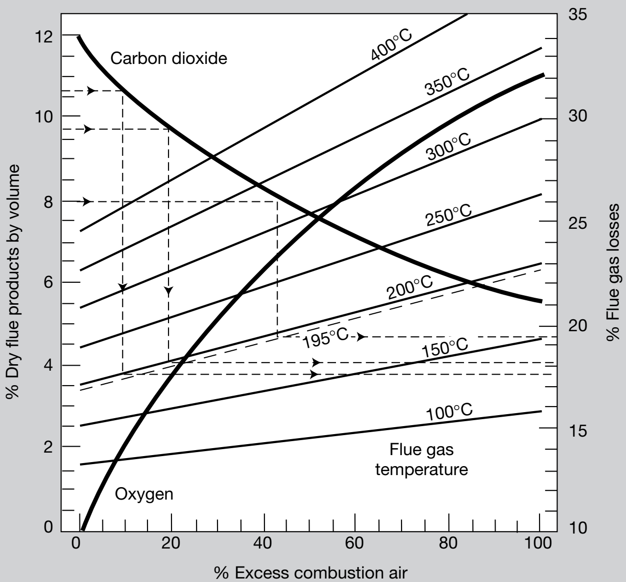

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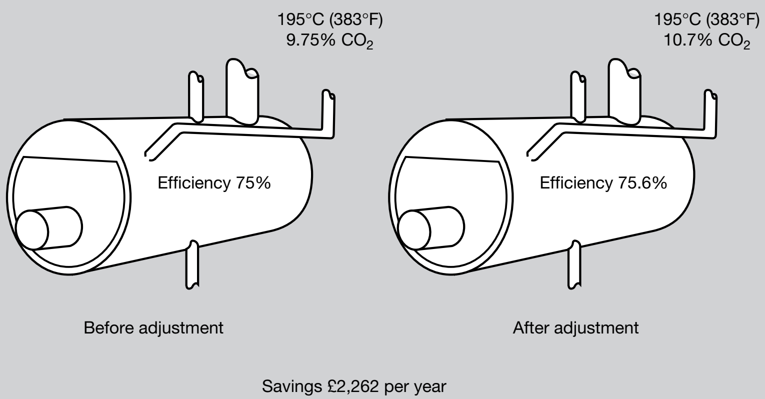
Fig 4 Change in efficiency due to flue gas composition change



Example showing the effect of fouled heat transfer surfaces

A 56ºC (100ºF) rise in the temperature of the flue gas will cause an increase in flue gas losses from 18% to 20.5%. For the Example Boiler, this would reduce efficiency by 2.5%, at an extra cost of:

$$£285{,}000 \times \frac{72.5 - 75}{72.5} = £9{,}828 \text{ per year.}$$

(see Fig 6)

This example is illustrated on Fig 5 to show how the graph is used.

type brick set boilers there may be difficulty in finding a sample point which is not affected by air ingress. Experienced personnel should be consulted to undertake testing in these circumstances.

- *Condition of heat transfer surfaces*

Providing that boiler tubes are initially clean and that combustion is not so far out of adjustment as to cause soot formation, gas firing should maintain clean heat transfer surfaces. Conditions giving rise to soot formation should be avoided at all times.

If, however, tubes do become fouled, for example due to malfunctioning during multi-fuel firing, the stack losses will increase and excess fuel will be used. Cleaning costs will be quickly repaid by the resulting fuel saving. The boiler manufacturer's advice should be sought on the frequency of cleaning.

- *Flue gas heat recovery systems*

The flue gases leaving boilers are at a temperature higher than that of the steam produced. Part of this heat may be recoverable, depending on the space availability, use of the recovered heat and the operational programme of the boiler plant. Some possible heat recovery

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systems are described below. The viability of each installation for a particular application can be obtained from the manufacturers.

- *Economisers*

  1 *Conventional economisers*

  Feed water heaters, termed economisers, can save up to 5% of the fuel used and are particularly suitable for use with gas-firing. The recovered heat can be used to pre-heat boiler feed water or combustion air. For dual-fuel applications, an economiser can be by-passed when firing on the other fuel.

  2 *Condensing economisers*

  As gas has a minimal sulphur content, it is possible for the flue gas exit temperatures to be below the water dewpoint temperature without causing significant corrosion problems. Energy savings of at least 10% are possible by using the recovered heat to pre-heat boiler feed water or combustion air. More information can be found in New Practice Report 59 - *The performance of a condensing economiser fitted to an industrial gas-fired steam boiler.*

- *Baffles*

  The installation of specially designed baffles into the flueway passes of older pattern cast iron sectional boilers can increase boiler efficiency by an average of 5%. Additional increases in boiler efficiency can be achieved by the improvement in combustion produced by installing the

Fig 5 Flue gas losses - natural gas - Effect of higher flue gas temperature

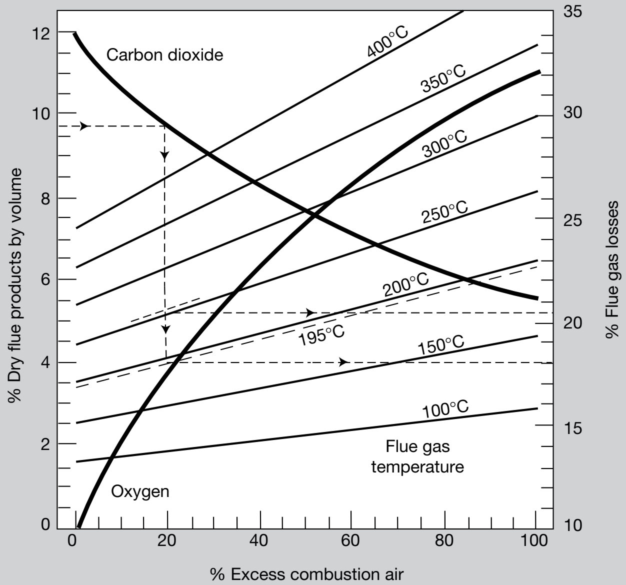

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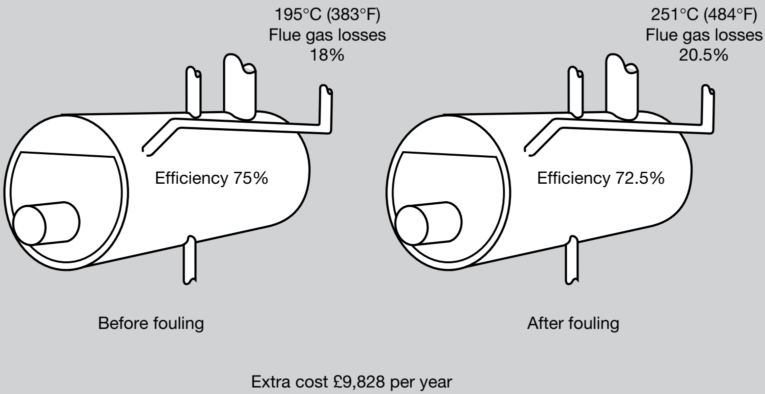
Fig 6 Change in efficiency due to flue gas temperature change



baffles on boilers operating with high excess air levels.

For older boilers the fitting of baffles is a very simple and cost-effective method of achieving both fuel and money savings, but for a modern boiler, with proper adjustment of excess air, baffles are unlikely to make any significant improvement.

- *Spray recuperators*

  In this recent development for use with gas-fired boilers, water is sprayed through the flue gases, thus gaining heat from the gases and also some of the latent heat of the water vapour content.

  These units can be installed in addition to an economiser or can be used as the sole means of heat recovery. There is, however, a maximum economic and practical temperature to which the water should be heated, and there also needs to be an appropriate application to use the considerable quantity of heated water for the installation to prove economic. For dual-fuel firing, the system can be taken out of use when firing on the other fuel, i.e. fuel oil, as in the case of an economiser.

- *Heat wheels*

  A heat wheel is a unit in which the flue gases pass through a segment of a revolving drum containing a large surface area which absorbs heat. The heated section then passes into an adjacent segment, and air is blown through to pick up the heat. This heated air can then be used for process purposes or for room heating.

- *Flue dampers*

  It may be economic in some cases to fit isolating dampers to individual boiler flues. In order to estimate savings, consideration should be given to the combination of boiler

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Example showing the effect of part-load running

If the load in the Example Boiler is supplied by two boilers running part-loaded at half of their maximum rating, and the true radiation loss is 2% at full load, then the total radiation loss will be doubled to 4%; this will add an extra £5,700 (2% of £285,000) to the annual fuel bill, compared with the situation where the load is supplied by one boiler at full load.

and burner, firing schedules and flue conditions. Manufacturers should be consulted and schemes carefully evaluated. Safety considerations must also be examined.

Radiation loss

Radiation loss refers to heat loss from the outside of the boiler. This heat loss is in fact a combination of radiation, convection and conduction loss, but for practical purposes the term radiation only is normally used when calculating boiler efficiency.

Radiation loss on modern boilers is usually 1% or less of the heat input at maximum rating. It may, however, be considerably higher on older boilers and it can be as high as 10% where insulation is in poor condition and the boiler is of an old design.

Radiation loss is not readily measurable on a boiler and has customarily been included in the unattributable losses to make up the heat balance. It is therefore often referred to as radiation and other losses and can appear higher than would be expected for actual surface losses alone.

Radiation loss is constant while the boiler is firing, because it is determined by the temperature of the boiler and not by its output of steam. When running under low-load conditions it represents a higher proportion of the total fuel used than under high fire conditions.

Firing schedules/boiler sequence control

The quantity and profile of steam required by a plant throughout the day and week should be reviewed frequently, and the minimum number of boilers should be used to supply the demand. It may be worth risking temporary loss or reduction of steam supply in the event of a boiler failure in order to run at optimum efficiency. An assessment should be made of the time required to bring a standby boiler on-line or to rectify the likely faults.

Where multi-boiler plant installations are in operation, significant fuel and energy savings can be made by installing a Boiler Sequence Control system. These are fully automatic, microprocessor-controlled systems which monitor and sequence on/off operations of boilers and associated equipment according to steam demand.

The valving-off of boilers not in continuous use should receive periodic examination. If boilers are required to stand for long periods, ‘blanks’ should be inserted between boiler isolating valves and connecting pipework flanges.

Centralised integrated control of boiler plant

The centralised integrated control of boiler plant is a combination of specific microprocessor control systems such as those previously referred to, comprising fuel-to-air ratio control and oxygen trim, coupled with a diagnostic system

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which indicates boiler and associated boiler plant faults. The advantages of centralised control are numerous, enabling all aspects of boiler plant operation to be optimised simultaneously. Maximum overall efficiency is therefore maintained and boiler down-time is kept to a minimum.

Variable speed control of combustion air fan

If the load characteristic of a large boiler plant is variable, then substantial energy savings are possible using a Variable Speed Drive (VSD) system.

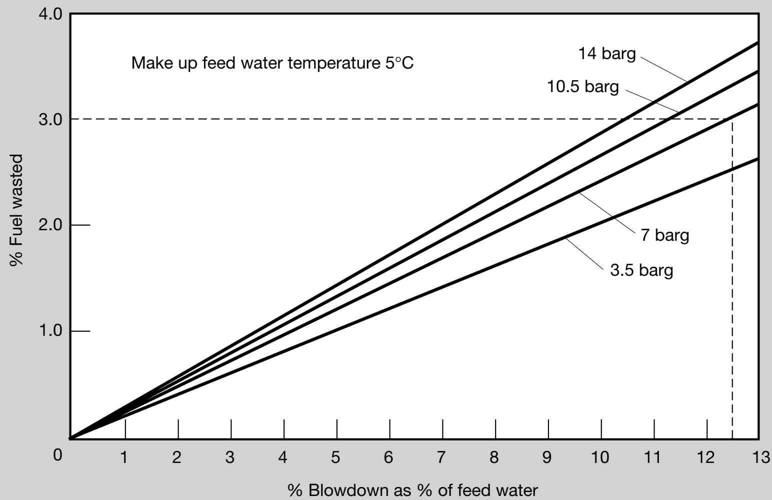
A VSD system will reproduce the operating characteristics of a fixed speed combustion air fan and adjustable damper arrangement, as well as reducing the average electrical demand of the fan motor by approximately 60%. The use of a VSD system has been shown to be cost-effective whilst at the same time maintaining good combustion conditions and high boiler efficiency. See Good Practice Case Study 35 - Variable speed drive on a boiler fan - for details of an industrial application, showing the savings achieved.

Combustion air pre-heat

Combustion air pre-heat is another potential energy saving technique worthy of consideration. The usual heat sources for combustion air pre-heating include:

- heat remaining in the gases;
- higher temperature air drawn from the top of the boiler house;
- heat recovered by drawing air over or through the boiler casing to reduce shell losses.

Fig 7 Percentage of fuel wasted in blowdown



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The thermal efficiency of a boiler plant could be increased by 1% if the combustion air temperature was raised by a further 20°C. Further information can be found in Good Practice Guide 30 - *Energy efficient operation of industrial boiler plant.*

Blowdown

Boiler blowdown is necessary to:

- remove sludge from precipitated salts; prevent the scaling up of tubes and tube plates on the water side;
- avoid priming and carry over into steam mains.

To avoid unnecessary loss of heat, blowdown should be kept as low as possible while still maintaining the recommended level of total dissolved solids. The loss of heat due to blowdown is shown in Fig 7. Part of this loss can be recovered by a heat exchanger, the useful heat being used to pre-heat feed water heat or other purposes.

A high blowdown loss may well justify expenditure on heat recovery equipment or water treatment plant. If all the factory condensate is returned to the hot well, blowdown can be drastically reduced.

Where more than one boiler is operated on an intermittent system, it is advantageous to stagger or automatically time the blowdown cycle in order to spread the availability of waste heat more evenly. This will enable waste heat recovery to be more economic, because the equipment required will be smaller and will run for a higher proportion of the time, thereby proving more cost-effective.

One of the most simple ways to recover heat from blowdown is through direct use of the flash steam, which forms due to evaporation as the pressure falls through the blowdown valve. This is pure water, with no dissolved solids, and can therefore be added directly to the make-up water for the boiler. Additional heat can be recovered from the remaining blowdown by installing a heat exchanger to pre-heat boiler feed water. (Fuel Efficiency Booklet 2 - *Steam* - covers this subject in greater detail.)

Example of the effect of blowdown

In the case of the Example Boiler, blowdown accounts for 3% of the losses in the boiler. This represents blowdown of approximately 12.5% of the evaporation rate; which is also approximately 12.5% of the feed water, and costs £8,550 per year in lost fuel, plus the cost of the feed water and the water treatment where applicable. This example is indicated on Fig 7 to show how the graph is used.

Feed water supply

- *Water treatment*

Chemical water treatment is necessary to:

- prevent scale formation in boilers and ancillary equipment which leads to higher flue gas temperature and lower boiler efficiency (Fuel Efficiency Booklet 2 - *Steam* - gives examples of heat transfer being affected by the formation of scale);
- control sludge and scale formation in the boiler and to reduce blowdown;
- reduce or eliminate corrosion of the boiler and steam mains (from carbon dioxide in the steam) which leads to higher maintenance costs;

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- avoid contamination of the steam by boiler water, which can be carried over due to foaming and priming;
- minimise corrosion due to dissolved oxygen in the feed water.

Adequate treatment should be given, following the advice of a competent water treatment specialist. Over-dosing can be avoided by ensuring that operatives are not heavy handed; and by switching off treatment pumps when boilers are not operating. Ideally, boiler dosing equipment should be controlled by the operation of the feed water pump.

Water treatment facilities should be appropriate to the requirements. To ensure this, more than one opinion and quotation should be obtained from water treatment firms, the boiler manufacturer and from the insurance company. The cheapest is not necessarily the best buy. Most of the water treatment should be carried out in plant external to the boiler.

If the quality of the water treatment is improved and/or the proportion of returned condensate is increased, this should reduce the amount of blowdown necessary. Total dissolved solid levels are easily checked by measuring water density (using a special hydrometer) and temperature. Boiler water test kits are cheap and relatively easy to use, and can be purchased through a water treatment specialist. Detailed recommendations on treatment can be found in BS 2486: 1978 - *Recommendations for treatment of water for land boilers.*

- *Condensate recovery*

  If feed water temperature is low, the cause should be discovered. It could be due to:

  - a low rate of condensate return;
  - lack of insulation on the condensate return pipes (though this may not be important in space heating systems);
  - losses from the feed water tank either as heat through tank walls or via overflows.

As much condensate as is economically possible should be returned from sources where there is no likelihood of contamination. This will save heat, make-up water and any chemicals used for water treatment, as well as reducing blowdown losses. The savings resulting from increased temperature of condensate return are shown in Fig 8.

Example of the possible savings from increased condensate return

If the feed water temperature in the Example Boiler is raised from 15.5ºC (60ºF) to 38ºC (100ºF) by increasing the amount of condensate returned at 38ºC (100ºF) from 25% to 100%, a saving of 3.2% of boiler fuel will result, worth £9,120 per year (see Fig 9). Further savings will also accrue due to an accompanying reduction in blowdown losses.

Where feed water contamination can occur, automatic dumping by monitoring the conductivity of the condensate is common. In large installations, several condensate returns may be monitored independently and only the affected sources dumped, avoiding the loss of all returns and identifying the route of contamination.

Without special arrangements, it is rarely possible to use feed water in excess of 82°C (180°F) due to cavitation problems on the feed pump. The feed water temperature can,

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Fig 8 Fuel saved by condensate return

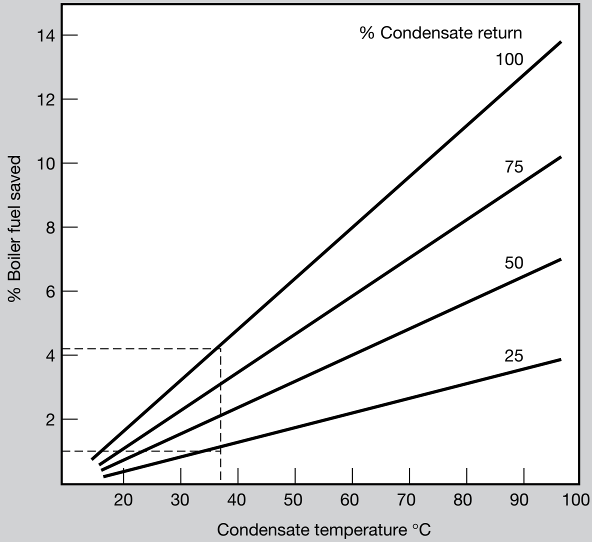
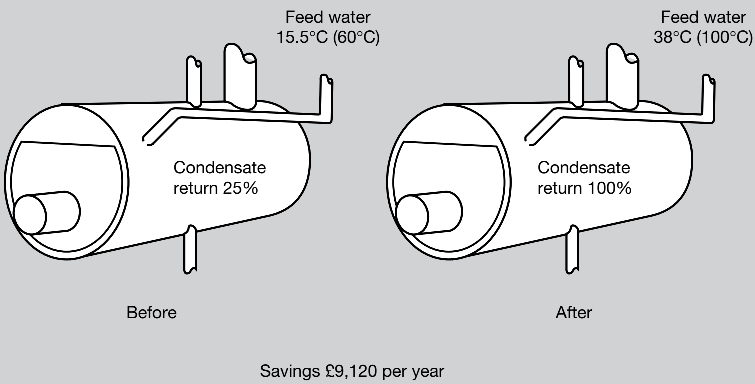


Fig 9 Change in operating costs due to extra condensate return



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however, be raised above this level after the pump if an economiser is fitted. When in doubt consult the boiler or feed pump manufacturer. Fuel Efficiency Booklet 2 - *Steam* - has a section on heat recovery techniques which covers this subject in more detail.

Steam and hot water services

- *Steam supply*

  Steam boilers should not be operated below the minimum pressure recommended by the manufacturer. If the steam using equipment requires a significantly lower pressure, consideration should be given to de-rating the boiler or replacing it. Alternatively the high pressure steam could be used in a steam turbine to generate electricity. These actions will minimise distribution heat losses. The pressure drop in the main steam lines up to the point of use will need to be checked so that the optimum initial pressure can be determined.

- *Header connections on boiler plant*

  Where more than two boilers are connected into a common header it is important that the layout is correct. Fig 10 shows correct and incorrect methods of connecting four boilers into a header.

  Incorrect connection can lead to the following sequence of events occurring. One or more boilers could receive an excess steam demand of up to 25%, e.g. boilers 3 and 4 in Fig 10a. Due to limited heat input, the boiler(s) will respond to this demand with a drop in pressure, accompanied by an expansion of the steam and water mixture in the boiler, resulting in foaming and carry over. In severe cases this can cause loss of water from boilers, leading to boiler lock-out due to low water, with the load then being thrust upon the remaining boilers. These in turn will become overloaded and the system cascade, locking out all the boilers at a time when their outputs are all needed. This effect is caused by the pressure loss along the header, which increases proportionally with the square of the steam flow.

  In Fig 10a, the pressure in the header will fall severely from the point of connection at boiler 1 to those at boilers 3 and 4, as the successive outputs of the boilers are added into the header; boilers 3 and 4 could become severely overloaded. The pressure difference, and hence boiler loading, between boilers 1 and 2 would be much less, about 5%, which the firing equipment could handle. To avoid problems, not more than two boilers should discharge into a header or sub-header, as shown in Fig 10b.

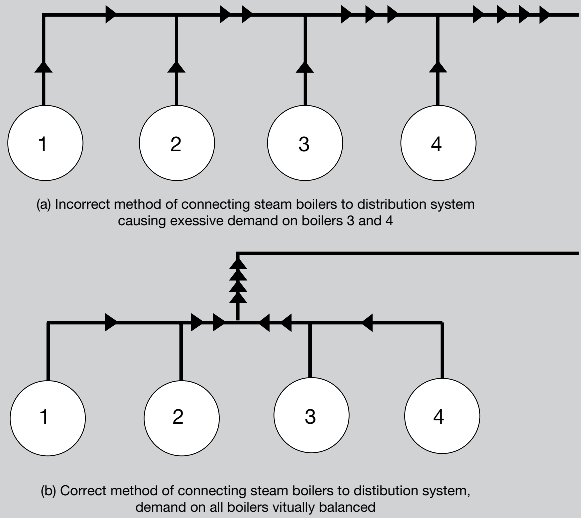
  Many installations have boilers incorrectly connected to the distribution system, resulting in the problems described. It is worthwhile changing the connections to overcome these problems. As a temporary measure, the outlets from all boilers can be fitted with limiting orifice plates designed to lose about 3 bar pressure at full boiler rating. Loading problems can exist with all boilers, irrespective of fuel used, and if allowed to persist can seriously affect the reliability and efficiency of the whole steam generating and using plant.

- *Pipework*

  All piping and valves conveying steam and condensate should be properly insulated and weatherproofed, except where they are

FACTORS AFFECTING THE EFFICIENT USE OF ENERGY

Fig 10 Methods of connecting steam boilers to a distribution system



exclusively part of a controlled heating system, and the steam supply should be turned off when there is no heating requirement. Insulating large diameter pipes pays off in a few weeks, and insulating small diameter pipes pays off in a few months.

Often in older installations steam valves and flanges were not insulated, but it is now economic to do so.

Procedures should be established such that insulation is examined regularly and promptly replaced where necessary, particularly on equipment or pipes which have had to be dismantled or repaired. The economic thickness of the insulation should be re-assessed at replacement; some insulation contractors and equipment suppliers may still be working on uneconomic thicknesses. Further information can be found in Fuel Efficiency Booklet 8 - *The economic thickness of insulation for hot pipes.*

Where cavitation may result from increased water temperature due to insulating feed water pipes, there should be an adequate head on the suction of the boiler feed pump.

Example of the effects of insulation

In the Example Boiler, 30 m (100 ft) of unlagged 80 mm (3 in) pipe carrying steam at 7 barg (100 psig) and 170°C (338°F) will lose heat at the rate equivalent to £2,700 per year.

An uninsulated valve is equivalent to 1 m (3 linear feet) of uninsulated pipe; at 7 barg (100 psig) an 80 mm (3 in) valve will lose heat equivalent to £80 per year. An uninsulated flange will lose half this.

CHECKLIST OF MONEY-SAVING PROCEDURES

4 CHECK LIST OF MONEY-SAVING PROCEDURES

1 Measure the output of steam from boilers either directly by means of a steam meter, or indirectly by metering the total boiler feed water and estimating the blowdown. The ratio of steam to fuel is the main measure of efficiency of the boiler and it should be measured and maintained at a high level, compatible with good practice.

2 Continuously log boiler performance so that signs of deterioration soon become evident, enabling corrective maintenance to be carried out. Examples of daily log sheets and weekly summary sheets for steam and hot water boilers are given in Figs 11, 12, 13 and 14.

3 Meter feed water.

4 Check steam meters occasionally, as their performance deteriorates with time due to erosion of the metering orifice or pitot head. Steam meters only give correct readings at the calibrated steam pressure - re-calibration is required if the steam pressure is changed, and the meter reading should be corrected for changes in steam volume. Further information can be found in Good Practice Guide 18 - *Reducing consumption costs by steam metering.*

5 Isolate pipelines not in use and disconnect redundant pipes. Regular surveys should be made, particularly if the pipework uses are frequently changed.

6 Ensure that accounting for input and output of energy in boilerhouses is as realistic as possible.

7 Improve housekeeping procedures, as these are likely to promote better working conditions and higher efficiencies in the boilerhouse.

8 Review the repair and maintenance procedures in the boilerhouse, especially where they affect the firing equipment, controls and instrumentation. There should be a regular routine for checking and cleaning boiler heat transfer surfaces or smoke tubes. Any instrumentation or equipment which is faulty and out of use, for example water meters, temperature indicators or recorders and economisers (where applicable), should be repaired and brought back into operation as quickly as possible.

9 Periodically check the state of furnace brickwork and flue. In older boiler installations, underground flues may need to be checked for water leakage.

10 Repair steam without delay. Such leaks not only waste energy but are also potential safety hazards.

11 Investigate the possibility of implementing heat recovery systems. See Good Practice Guide 30 - *Energy efficient operation of industrial boiler plant* - for more detailed information on available techniques.

DAILY LOG SHEET - STEAM BOILERS

Fig 11 Example daily log sheet for steam boilers

Date:

Plant:

Time	Boiler No	Steam		Water				Flue gases			Draught		Fuel					Air	Comments
		Presure (bar)	Temp. (°C)	Temp. econ. inlet (°C)	Temp. boiler inlet (°C)	Meter reading feed water (litres)	Meter reading make-up water (litres)	Temp. boiler outlet (°C)	Temp. econ. outlet (°C)	CO_2 or O_2 (%)	Pressure in combustion chamber (bar)	Pressure at boiler outlet (bar)	Flow meter (kg.m^3 or litres)	Return meter (kg.m^3 or litres)	Flow temp. (°C)	Return temp. (°C)	Ashes (kg)	Outside temp. (°C)	
Total																			
No of readings																			
Average																			

Daily Summary

Fuel type and grade . . . .
. . . .
Fuel used (metered) . . . .
Fuel used. kg
Evaporation of steam: total . . . . . . kg
Ashes: total . . . . kg

Density (20/20)..
or Calorific Value ....kJ/kg or kJ/m^3
Fuel used (corrected to 20°C)...
....
Evaporation of steam per kg of fuel................................ kg
= ....% of fuel

Feed water: Meter reading (start of day)..kg
Meter reading (end of day)...kg
Difference..kg
Make-up water ....kg = ...% of evaporation
Blowdown (total) time ....Quantity ....

Operators on duty:	Shift 1	Shift 2	Shift 3	Comments

DAILY LOG SHEET - HOT WATER BOILERS

Fig 12 Example daily log sheet for hot water boilers

Date: Plant:

Time	Boiler No	Water					Flue gases			Draught		Fuel					Air	Comments
		Working pressure (bar)	Temp. boiler outlet (°C)	Temp. econ. inlet (°C)	Temp. boiler inlet (°C)	Meter reading (kJ or litres)	Temp. boiler outlet (°C)	Temp. econ. outlet (°C)	CO_2 or O_2 (%)	Pressure in combustion chamber (bar)	Pressure at boiler outlet (bar)	Flow meter (kg.m^3 or litres)	Return meter (kg.m^3 or litres)	Flow temp. (°C)	Return temp. (°C)	Ashes (kg)	Outside temp. (°C)	
Total																		
No of readings																		
Average																		

Daily Summary

Fuel type and grade . . . . Density (20/20)..

. . . . or Calorific Value ....kJ/kg or kJ/m^3

Fuel used (metered) . . . . Fuel used (corrected to 20°C)...

Fuel used. kg ....

Evaporation of steam: total . . . . . . kg

Ashes: total . . . . kg = ...% of fuel

Total Water circulated ....litres

Average temperature difference...°C

Total heat output...kJ

Total heat per kg of fuel ....kJ

Make-up water...litres = ... % of total

Operators on duty:	Shift 1	Shift 2	Shift 3	Comments

WEEKLY SUMMARY SHEET - STEAM BOILERS

Fig 13 Example weekly summary sheet for steam boilers

Week Commencing				Plant			
Date	Fuel consumed (kg)	Ashes (kg or %)	Water evaporated (kg)	Evaporation per kg or m^3 of fuel (kg)	Make-up water (% of total)	Hours operating	Comments
Total							
No of readings							
Average							

Total amount of fuel used .... kg at £ .... per kg

.... litres (corrected to 20^0C) at £ .... per litre (or cubic metre = 10^3 litres)

Weekly total fuel costs £..

Costs of fuel for evaporating 1000 kg of water £..

Comments on weekly summary ....

....

....

WEEKLY SUMMARY SHEET - HOT WATER BOILERS

Fig 14 Example weekly summary sheet for hot water boilers

Week Commencing

Plant

Date	Fuel consumed (kg)	Ashes (kg or %)	Total water circulated (kg)	Average temperature difference (^{0}C)	Total heat output (kJ)	Heat output per kg or m^3 fuel kJ	Make-up water (% of total)	Hours operating	Comments
Total									
No of readings									
Average									

Total amount of fuel used .... kg at £ ....per kg

.... litres (corrected to 20^{0}C) at £ .... per litre (or cubic metre = 10^3 litres)

Weekly total fuel costs £ ....

Costs of fuel per MJ £ ....

Comments on weekly summary ....

....

....

SOURCES OF FURTHER INFORMATION

5 SOURCES OF FURTHER INFORMATION

■ *British Standards:*

BS 845: 1987 -

Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids

BS 2486: 1978 -

Recommendations for treatment of water for land boilers

Copies of these British Standards are available from:

British Standards Institution
Sales Department
Linford Wood
Milton Keynes
MK14 6LE

■ *The latest news in energy efficiency technology*

Energy Management is a free journal issued on behalf of the Department of the Environment which contains information on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation. It also contains information addresses and contacts for the regional Government Offices.

Copies of Energy Management can be obtained through:

Emap Maclaren Limited
Maclaren House
19 Scarbrook Road
Croydon
Surrey CR9 1QH

■ *DOE Publications:*

Good Practice Guide 18 - *Reducing energy consumption costs by steam metering*

Good Practice Guide 30 - *Energy efficient operation of industrial boiler plant*

Good Practice Case Study 35 - *Variable speed drive on a boiler fan*

Good Practice Case Study 153 - *Differential drainage and boiler return system*

New Practice Final Profile 59 - *The performance of a condensing economiser fitted to an industrial gas-fired steam boiler*

Copies of these publications and other literature applicable to the economic use of gas-fired boiler plant are available from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxon
OX11 0RA
Tel: 01235 436747
Fax: 01235 433066

Information is also available through regional Government Offices.

Titles in the Fuel Efficiency Booklet series are:

1 *Energy audits for industry*

1B *Energy audits for buildings*

2 *Steam*

3 *Economic use of fired space heaters for industry and commerce*

4 *Compressed air and energy use*

7 *Degree days*

8 *The economic thickness of insulation for hot pipes*

9 *Economic use of electricity in industry*

9B *Economic use of electricity in buildings*

10 *Controls and energy savings*

11 *The economic use of refrigeration plant*

12 *Energy management and good lighting practices*

13 *Waste avoidance methods*

14 *Economic use of oil-fired boiler plant*

15 *Economic use of gas-fired boiler plant*

16 *Economic thickness of insulation for existing industrial buildings*

17 *Economic use of coal-fired boiler plant*

19 *Process plant insulation and fuel efficiency*

20 *Energy efficiency in road transport*

Fuel Efficiency booklets are part of the Energy Efficiency Best Practice programme, an initiative aimed at advancing and promoting ways of improving the efficiency with which energy is used in the UK.

For copies of Fuel Efficiency booklets or further information please contact the addresses below.

Overseas customers please remit £3 per copy (minimum of £6) to the ETSU or BRECSU address with order to cover cost of packaging and posting. Please make cheques, drafts or money orders payable to ETSU or BRECSU, as appropriate.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related publications please contact:
Enquiries Bureau
BRECSU
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Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport publications please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Fax01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.